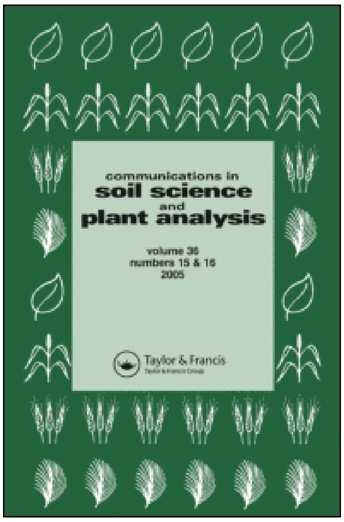

Communications in Soil Science and Plant Analysis
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597241

Petiole and Soil Nitrogen Concentrations during the Growing Season of Two Potato Cultivars as Influenced by Different Nitrogen-Management Practices

A. K. Alva [a]
[a] USDA-ARS, Prosser, Washington, USA

Online Publication Date: 01 February 2007

To cite this Article Alva, A. K.(2007)'Petiole and Soil Nitrogen Concentrations during the Growing Season of Two Potato Cultivars as Influenced by Different Nitrogen-Management Practices',Communications in Soil Science and Plant Analysis,38:3,403 — 421

To link to this Article: DOI: 10.1080/00103620601172415

URL: http://dx.doi.org/10.1080/00103620601172415

Communications in Soil Science and Plant Analysis, 38: 403–421, 2007

ISSN 0010-3624 print/1532-2416 online
DOI: 10.1080/00103620601172415

Petiole and Soil Nitrogen Concentrations during the Growing Season of Two Potato Cultivars as Influenced by Different Nitrogen-Management Practices

A. K. Alva
USDA-ARS, Prosser, Washington, USA

Abstract: Fine-tuning potato nitrogen (N) management for irrigated sandy soils is a desirable goal to optimize the production and minimize negative impacts on the environment. Effects of different rates of preplant N (PP-N) applications and different rates and frequencies of in-season N (IS-N) for two potato cultivars were evaluated for 2 years (2001 and 2002) in a Quincy fine sand (mixed, mesic, Xeric Torripsamments) in the Pacific Northwest (PNW). In the 2001 experiment, the petiole nitrate (NO_3-N) concentrations in both the cultivars were in the optimum range in the samples taken 22 days after emergence (DAE). In the subsequent sampling, the petiole NO_3-N concentrations showed a wide range proportional to the rates of IS-N. In the 2002 experiment, the petiole NO_3-N concentrations were in the excess range in most treatments until about 51 DAE in both the cultivars, followed by a decline in concentrations to the low range. The petiole phosphorus (P) and potassium (K) concentrations were mostly above the excess range in both the cultivars over the entire sampling period. The soil N data showed that the transformation of urea N was quite rapid and that the extractable ammonium (NH_4-N) and NO_3-N concentrations in the soil returned to the background levels within 90 days after the PP-N application. The results of this study demonstrate a rapid transformation of preplant applied urea N into NH_4-N and NO_3-N and depletion of the available N in the top 120 cm of soil. This, in turn, supports the need for IS-N applications to meet the crop N requirement during the later growing period.

Keywords: Center pivot irrigation, in-season nitrogen, nitrate leaching, nitrate pollution of groundwater, preplant nitrogen, tuber quality

Received 5 December 2003, Accepted 9 February 2006
Address correspondence to A. K. Alva, Research Leader, USDA-ARS, 24106 North Bunn Road, Prosser, WA 99350, USA. E-mail: aalva@pars.ars.usda.gov

INTRODUCTION

A nitrogen (N) fertilizer program based on monitoring of soil and/or plant to determine the crop N requirement is desirable to improve N-uptake efficiency and to minimize N losses. Analysis of soil for extractable N, particularly in sandy soils, is generally a poor indicator of plant-available N over the entire duration of crop growth. Several studies have demonstrated good correlation between the relative potato (*Solanum tuberosum* L.) yields and petiole dry matter or sap nitrate (NO_3^-) levels (Roberts and Cheng, 1988; Westcott, Stewart, and Lund 1991; Westcott, Rosen, and Inskeep 1993; Williams and Meir 1990; Vitosh and Silva 1994, 1996; Porter and Sisson, 1991). Petiole NO_3^- levels have been recommended for use along with soil analysis as a basis to monitor potato N requirement (Gardener and Jones 1975; Westermann 1993; Dean 1993). Analysis of soil N and petiole NO_3-N levels provide some basis for evaluation of fate and transport of N in the soil and the plant N-status response to various N-management practices.

Petiole analyses have also been used to determine the status of other nutrients in potato plants. For example, Roberts and Dow (1982) conducted a 2-year field study on the Russet Burbank potato cultivar with different rates of phosphorus (P) (0 to 269 kg ha^{-1}) incorporated in the soil at planting. They reported critical P concentrations in the petiole of 0.38% to 0.45% in June, which decreased gradually to 0.14% to 0.17% 10 weeks later.

Agricultural crop production practices could impact the environment, in particular, possible nonpoint source pollution of water from agricultural chemicals. Soil-applied pesticides and soluble nutrients (primarily N), applied routinely for crop production, may leach below the root zone of crops in sandy soils, particularly under excess irrigation or rainfall. These chemicals, which are transported below the root zone in the soil solution, could contribute to groundwater degradation. This is one of the mechanisms that contribute to NO_3-N pollution of groundwater (U.S. Dept. Health, Education, and Welfare 1962). Concentrations of NO_3-N of more than 10 mg L^{-1} is a violation of the drinking water quality standards. Nitrate contamination of groundwater may be mitigated by development and adaptation of N best management practices (N BMP) for various crops to minimize leaching losses. Monitoring of soil and/or plants to determine the crop N requirement is one of the approaches to develop NBMP in an effort to minimize applications in excess of crop requirement, which could contribute to N leaching.

Total potato production in the United State is 21×10^6 metric tons (ranks fourth in the world) on 517×10^3 hectares (National Potato Council 2004). Potato production in the Pacific Northwest (PNW), including Washington, Oregon, and Idaho, accounts for 55% of the total production in the United States. The Columbia Basin region of the PNW is well suited for high production of high-quality processing potato. Production in this region is generally on sandy soils and is highly dependent on irrigation, supplied primarily by center pivot. The potato industry in the PNW has changed in recent years. Historically, Russet Burbank was the major cultivar used. However, in recent years new cultivars such as Ranger Russet and Umatilla Russet have been grown in an increasing proportion of the potato acreage. During 1996 to 2005, the acreage under Ranger Russet increased from 8.7 to 16%, 3.6 to 25.3%, and 2.7 to 15% in Washington, Oregon, and Idaho, respectively (Washington State Potato Commission 2005, unpublished data). Likewise, Umatilla Russet was grown in 2005 on 10.8 and 2.1% of the total potato acreage in Washington and Oregon, respectively. Despite a gradual increase in adoption of these new cultivars, very little is known about optimal N management for these cultivars in the PNW. Furthermore, a recent groundwater monitoring study conducted by the U.S. Geological Survey (USGS) revealed an increasing trend of potential for nonpoint source nitrate contamination of groundwater in the Columbia Basin region (USGS 2004). Thus, there is a need to re-evaluate the current N-management practices for major crops, including potatoes, in this production region in an effort to fine-tune the N-management practices for major potato cultivars to minimize N losses, without adversely impacting the tuber yields and quality.

Two years (2001–2002) of field investigations have been conducted on the evaluation of different preplant and in-season N (PP-N and IS-N) management practices on Ranger Russet and Umatilla Russet potato cultivars. The treatments included different rates of soil applied N at planting (56, 112, or 168 kg ha^{-1} N) with the rest of the N (168, 224, or 280 kg N ha^{-1}) applied as fertigation (2, 3, 5, or 10 applications), 3 weeks following the seedling emergence, for a total of 336 kg N ha^{-1}. A high N rate (448 kg N ha^{-1}) treatment was also evaluated with 112 and 336 kg N ha^{-1} at planting and in-season, respectively. The tuber yields ranged from 62.3 to 74.7 and 63.9 to 72.3 Mg ha^{-1} for Ranger Russet and Umatilla Russet, respectively in 2001. In 2002, the corresponding tuber yields were 63.2 to 67.3 and 62.9 to 66.8 Mg ha^{-1} (Alva 2004). Different rates of PP-N as well as rates and frequencies of IS-N application had no significant effects on total as well as different size grade tuber yields of both cultivars. The objective of this study was to evaluate the changes in petiole NO_3-N concentrations as well as soil-extractable N levels during the two growing seasons as influenced by different N-management practices, described previously, for two potato cultivars.

MATERIALS AND METHODS

Field experiments were conducted in a Quincy fine sand (mixed, mesic Xeric Torripsamments; Table 1) in Benton County, Washington, under commercial production conditions using a center pivot irrigation system. This region is characterized by dry climate with annual precipitation of about 180 mm. The precipitation is primarily during the winter; therefore, spring crops are totally dependent on irrigation. Typical rotation practice followed in this region is potato–wheat–corn–corn. Accordingly, in this experiment, potato

Table 1. Bulk density and particle-size distribution of the Quincy fine sand at various depths

Soil depth (cm)	Bulk Density ($kg \cdot m^{-3}$)	Particle size distribution ($g \cdot kg^{-1}$)		
		Sand	Silt	Clay
0–10	1.33	917	56	27
10–30	1.54	927	52	21
30–60	1.61	936	48	16
60–90	1.60	928	48	24
90–120	1.58	948	38	14

Source: [Alva (2004)].

was planted following 2 years of field corn. Current industry standard field equipment was used to cultivate the soil and plant the crop. Potato (cv. Ranger Russet and Umatilla Russet) seed pieces were planted using a six-row commercial planter (86.4-cm row spacing × 25.4-cm plant spacing, i.e. 45,600 plants per hectare) on 20- to 30-cm raised beds. Preplant soil test P and potassium (K) levels were more than 20 and 240 mg kg^{-1}, respectively. These P and K levels are considered excessive (Lang et al. 1999); therefore, none was applied.

Soil core samples were taken from the top 30 cm at random locations within the experiment site prior to land preparation each year for analysis of residual soil N concentrations. Soil samples were air dried, extracted in 2M potassium chloride (KCl), and concentrations of NO_3-N and NH_4-N were measured using rapid flow auto-analyzer (Flow Injection Analyzer 8000; Lachat Instruments, Milwaukee, WI). This provided an estimate of residual available soil N at the time of planting. The industry standard cultural practices, including irrigation management, herbicide, and pesticide application programs (Dow et al. 1974; Lang et al. 1999; Washington State Cooperative Extension 2003a, 2003b, 2003c) were followed to keep consistency with the commercial practices in the region. Evapotranspiration (ET) and irrigation amounts during the 2001 and 2002 growing season are shown in Figures 1 and 2.

Year 2001 Experiment

Ranger Russet and Umatilla Russet cultivars were planted on 30 March 2001. Emergence of seedlings completed on 11 May 2001. Three PP-N rates were evaluated at either (i) 56, (ii) 112, or (iii) 168 kg N ha^{-1} at similar total N rate of 336 kg ha^{-1} for the whole growing period (Table 2). The balance between the total and PP-N rate was applied as IS-N as shown in Table 2. An additional treatment (iv) with 112 and 336 kg N ha^{-1} as preplant and in-season rates, respectively, was also included to examine the effects of high

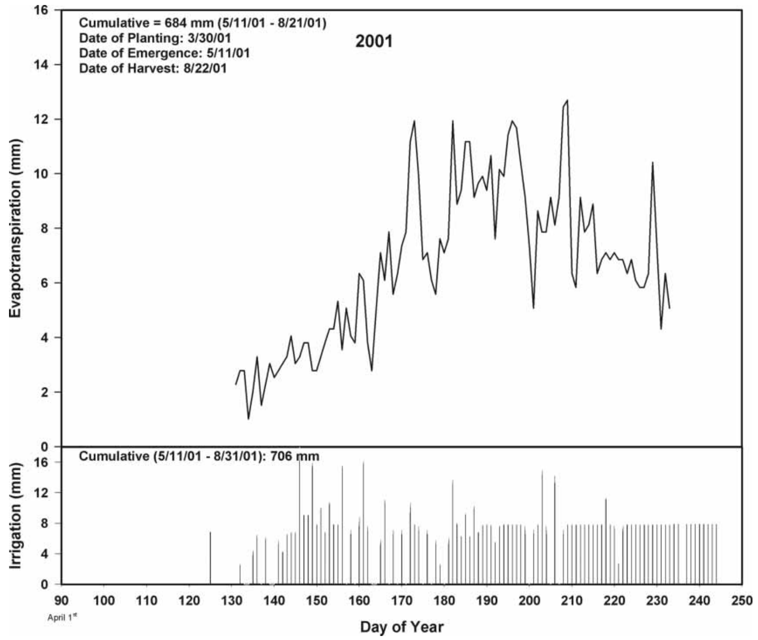

Figure 1. Evapotranspiration and irrigation amounts during potato (Ranger Russet and Umatilla Russet cultivars) growing season, 2001, in south-central Washington (representing the Columbia Basin production region). A center pivot irrigation system was used with 80% application efficiency.

total N rate of 448 kg N ha^{-1}. The residual soil N (based on the 30-cm-depth sampling) was 56 kg N ha^{-1}. Therefore, the PP-N application was adjusted to 0, 56, and 112 kg N ha^{-1} for the above three N rates, respectively. Urea-N (46% N) was broadcasted to attain the above PP-N rates and incorporated during land preparation. The IS-N rates for the four main treatments were 280, 224, 168, and 336 kg N ha^{-1}, respectively. All treatments received three blanket fertigations of 50, 34, and 34 kg N ha^{-1} per application, respectively, on 10, 18, and 21 days after emergence (DAE). The remainder of the total N [i.e., 162, 106, 50, and 218 kg N ha^{-1} for the treatments (i) through (iv) above] was applied in variable frequencies of either 2, 3, or 5 equal doses in 7-day intervals, starting 28 DAE. Therefore, the variable frequency IS-N rates per application varied from 32.4 to 81, 21.2 to 53, 10 to 25, and 43.6 to 109 kg ha^{-1}, respectively, for the treatments (i) through (iv) depending on the application frequency treatments. All IS-N applications were done using UAN (32% N) on the foliage, immediately followed by irrigation to wash the foliage.

The experiment was conducted using a split-plot design with four replications. The main treatments were PP-N rates, and the subtreatments were IS-N rates and frequencies. The subplot size was six rows (5.2 m), each 12.2 m

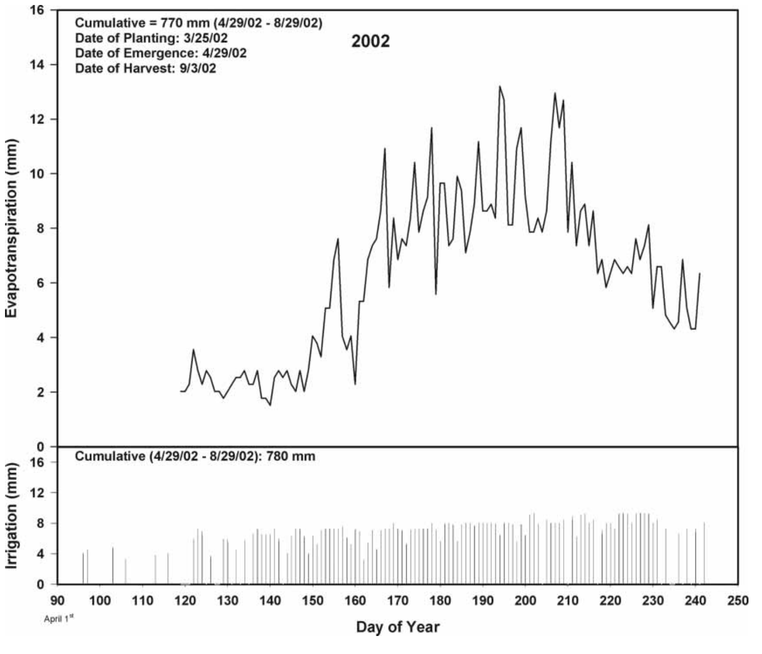

Figure 2. Evapotranspiration and irrigation amounts during potato (Ranger Russet and Umatilla Russet cultivars) growing season, 2002, in south-central Washington (representing the Columbia Basin production region). A center pivot irrigation system was used with 80% application efficiency.

long. Tuber yield was measured from two middle rows of 6.1 m each per plot. Electronic tuber size grading equipment (Lectro Tek Services, Inc., Wenatchee, WA) was used to separate the tubers into size classes of less than 113 g, 113–228 g, 228–283 g, more than 283 g per tuber, and U.S. no. 2 plus culls. The proportion of different size grade tubers in the plot yield was used to calculate the per hectare yields of tubers in different size grades.

Year 2002 Experiment

The two cultivars were planted on 25 March 2002. The seedling emergence was completed on 29 April 2002. This was a repeat of the 2001 experiment, except that no blanket in-season fertigations were done and that in-season N fertigation was evaluated at either 5 or 10 applications at 7-day interval between each of the applications, which began 4 weeks after emergence (WAE) (Table 3). The application of IS-N lasted 8 to 13 WAE for the 5- and 10- frequency treatments, respectively. Residual soil N in the 30 cm depth soil sampled prior to land preparation was negligible; therefore, the PP-N rates for the four main treatments (Table 3) were applied as urea and

Table 2. Pre-plant N rates, and rates and schedule of in-season N applications for two potato cultivars in the 2001 experiment

Total N for the growing season (kg ha^{-1})	Residual soil N at planting (kg ha^{-1})	Preplant N applied (kg ha^{-1})	In-season N applied (kg ha^{-1})	Blanket in-season N (kg ha^{-1})			In-season N at either 2, 3, or 5 applications[a]
				10 DAE	18 DAE	21 DAE	
336	56	0	280	50	34	34	162
336	56	56	224	50	34	34	106
336	56	112	168	50	34	34	50
448	56	112	336	50	34	34	218

[a]Began 4 weeks after emergence; in-season N applications done (i) two appl. frequency, 6/13/01 and 6/20/01; (ii) three appl. frequency, as in (i) plus 6/27/01; (iii) five appl. frequency, as in (ii) plus 7/3/01 and 7/10/01.

Table 3. Total and preplant N rates for the four main treatments and schedule and N rates of in-season (IS) fertigations for two potato cultivars in the 2002 experiment

N rate (kg ha^{-1})					N rates applied on a weekly basis (kg ha^{-1})									
Total	Residual soil N at planting	Pre-plant N applied	In-season N applied	IS Freq.	3 WAE[a]	4 WAE	5 WAE	6 WAE	7 WAE	8 WAE	9 WAE	10 WAE	11 WAE	12 WAE
336	0	56	280	5	22.4	33.6 + 33.6	44.8 + 44.8	33.6 + 33.6	33.6					
				10	11.2	22.4	33.6	33.6	44.8	44.8	33.6	33.6	11.2	11.2
336	0	112	224	5	22.4	33.6 + 22.4	33.6 + 33.6	33.6 + 22.4	22.4					
				10	11.2	11.2	33.6	33.6	33.6	33.6	22.4	22.4	11.2	11.2
336	0	168	168	5	22.4	22.4 + 22.4	22.4 + 22.4	22.4 + 22.4	11.2					
				10	11.2	11.2	22.4	22.4	22.4	22.4	22.4	11.2	11.2	11.2
448	0	112	336	5	33.6	44.8 + 33.6	56.0 + 56.0	44.8 + 33.6	33.6					
				10	11.2	22.4	33.6	44.8	56.0	56.0	44.8	33.6	22.4	11.2

[a]Weeks 4, 5, and 6: Two applications were made for the five in-season frequency treatments to avoid application of high N rate at one time to minimize potential foliar burn.

incorporated with soil during land preparation. A split-plot design was followed with four replications. The plot size and procedure of tuber yield estimation and evaluation of tuber size grades were similar to those explained for the 2001 experiment.

Soil Sampling and Analysis

Soil samples were taken from all plots in 30-cm-depth increments down to 120 cm on 14, 37, 72, 104, 132, and 188 days after PP-N application (DAA) corresponds to 52 and 29 days prior to seedling emergence (DPE) and 6, 38, 66, and 122 DAE of PP-N in the year 2001. In 2002, soil samples were taken on 28, 57, 88, 118, 145, and 193 DAA of PP-N (i.e., 18 DPE and 11, 42, 72, 99, and 147 DAE). Three soil cores (2.5-cm-diameter bucket auger) were taken for each plot at each of the depths at each sampling. These soil cores were thoroughly mixed, and a subsample was placed in a Ziploc® plastic bag and stored in an ice chest with dry ice during sample transportation to the laboratory. These samples were stored in a refrigerator until further analysis. The gravimetric soil water content in the soil sample was measured. The field moist soil sample was weighed out as 2.5 g into 50-mL polystylene centrifuge bottles, and 25 mL of 2 M KCl was added. The centrifuge bottles were stoppered and shaken for 30 min in an end-over-end shaker. The suspension was centrifuged for 10 min at 3000 RPM, and the supernatant was filtered through Whatman no. 42 filter paper. The concentrations of NH_4-N and NO_3-N were measured using a rapid flow analyzer (Flow Injection Analyzer 8000; Lachat Instruments, Milwaukee, WI). These concentrations were then calculated on oven-dry soil weight basis using the gravimetric soil moisture content.

Petiole Sampling and Analysis

The petiole from the fourth fully expanded leaflet was sampled from 15 to 20 plants per plot on 22, 36, 43, 50, 57, and 65 DAE in 2001. In the 2002 experiment, petiole samples were taken on 37, 44, 51, 58, 65, 72, 80, and 86 DAE. Petiole samples were dried at 72°C and ground. The ground petiole tissue was extracted in 4% acetic acid (0.2-g ground sample in 50-mL 4% acetic acid) and concentration of NO_3-N was analyzed using a rapid flow analyzer; that of P and K were analyzed using inductively coupled plasma argon emission spectroscopy (ICPAES; Perkin Elmer, Optima 3000; Perkin Elmer Analytical Services, Boston, MA).

RESULTS AND DISCUSSION

The optimal ranges of NO_3-N in petiole are 1.5 to 2.6%, 1.2 to 2.0%, and 0.6 to 1.0% during tuber initiation, tuber bulking, and tuber maturation stages, respectively (Lang et al. 1999). The changes in petiole NO_3-N concentrations during the 2001 and 2002 growing seasons, as well as the tuber yields for the respective N-management treatments, are shown in Figures 3 and 4. The tuber yields of both cultivars in both years were not significantly influenced by PP-N rate or rate and frequency of IS-N applications (Alva 2004). This was also true for petiole NO_3-N concentrations of both cultivars in both years.

The results of the 2001 study showed that for Ranger Russet cultivar, petiole NO_3-N concentrations were below the critical low limit on all N treatments during 30 to 45 DAE (Figure 3). Subsequently, the petiole NO_3-N concentrations increased above the critical low concentration limit in two N treatments that received IS-N rates of equal to or greater than 280 kg N ha^{-1}. In Umatilla Russet cultivar, with 112 and 168 kg N ha^{-1} PP-N rate treatments, the petiole NO_3-N concentrations were below the critical low limit during most of the growth period. In the remaining two treatments, the petiole NO_3-N concentrations were mostly either within the optimum or above the excess concentration limits. In 2002, the petiole NO_3-N concentrations were above the critical concentration until about 51 DAE. During the remainder of the growing period, the concentrations decreased sharply below the critical low concentration limit (Figure 4).

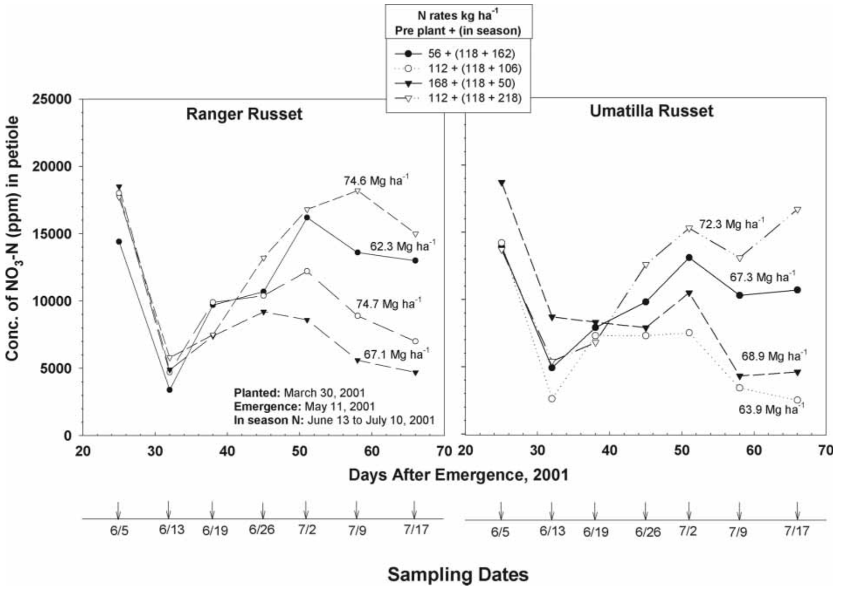

Figure 3. Changes in petiole NO_3-N concentrations in Ranger Russet and Umatilla Russet potato cultivars during the 2001 growing season as influenced by different preplant N rates and rates and frequencies of in-season N application. Total tuber yields for each treatment (means across N-application-frequency treatments within each N-rate treatment and replication) are also shown.

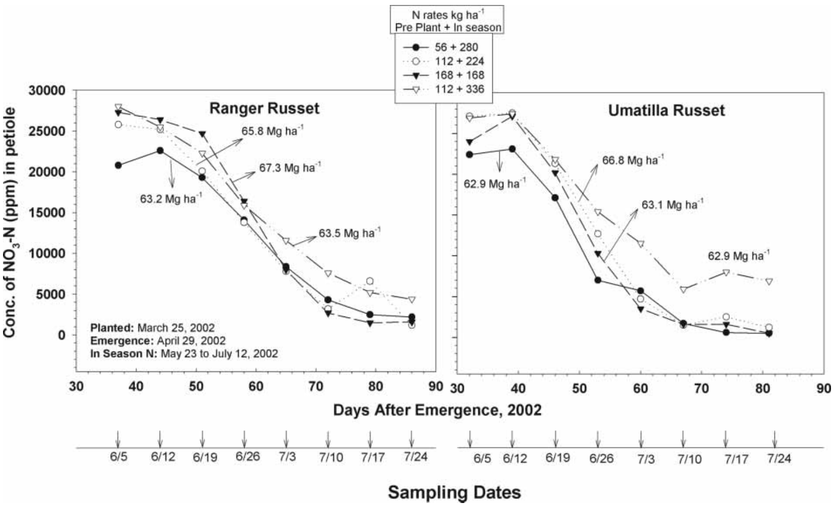

Figure 4. Changes in petiole NO_3–N concentrations in Ranger Russet and Umatilla Russet potato cultivars during the 2002 growing season as influenced by different preplant N rates and rates and frequencies of in-season N application. Total tuber yields for each treatment (means across N application frequency treatments within each N rate treatment and replication) are also shown.

The optimal ranges of petiole K concentrations during tuber initiation, bulking, and maturation growth stages are 8–11%, 6–9%, and 4–6%, respectively (Lang et al. 1999). The petiole K concentrations in the year 2001 experiment were well above the recommended critical excess limit (8.0%) for all samplings and for both cultivars (data not presented). Petiole K concentrations were not significantly influenced by the different N-management treatments. The petiole K concentration decreased over time for the Umatilla Russet, whereas those of Ranger Russet remained relatively similar across the entire sampling period. In the 2002 experiment, petiole K concentrations showed a gradual decrease from about 13.0% to 9.0% during the sampling period, in both the cultivars (data not presented). All petiole K concentrations were above the critical excess limit, in both the cultivars, over the entire sampling period.

The range of optimal P concentrations in the petiole is 0.16% to 0.24%. Across all N treatments in the 2001 experiment, the petiole P concentrations were in the range of 0.39 to 0.43% and 0.34 to 0.62% in the samples taken 37 DAE for the Ranger Russet and Umatilla Russet cultivars, respectively. These concentrations decreased to 0.19 to 0.23% and 0.10 to 0.22%, respectively, on 86 DAE (data not presented). The petiole P concentrations for all treatments across both cultivars were above the recommended critical excess limit until 51 DAE. The petiole P concentrations were within the optimum range for most treatments across both cultivars. In the 2002 experiment, the petiole P concentrations in the 37-DAE sampling were in the range of 0.43 to 0.48% and 0.43 to 0.46% for the Ranger Russet and Umatilla Russet cultivars, respectively (data not presented). With the growth of the plants, the petiole P concentrations changed very little until 65 DAE and then decreased to 0.22 to 0.28% in Ranger Russet and 0.17 to 0.27% in Umatilla Russet for the respective cultivars on 86 DAE.

Distribution of soil N forms in the soil profile over time is an indication of N transformation and transport in the soil as a result of PP-N and IS-N applications. This is influenced by a number of factors in addition to the rate, source, and time of N applications. The PP-N was applied in urea form, which undergoes transformation into ammonium and nitrate. This transformation is a relatively fast reaction under the ideal temperature and soil moisture conditions (Knight and Sparrow 1993; Yadav et al. 1987; Sankhayan and Shukla 1976; Khakural and Alva 1996).

In the 2001 experiment, the first soil sampling was taken 14 DAA of PP-N. This was 52 DPE. In the first soil sampling, the KCl-extractable NH_4-N concentrations in the top 30 cm of soil increased to about 5–7 mg kg^{-1} in the 112 or 168 kg ha^{-1} PP-N treatments (Figure 5). By 37 DAA of PP-N (or 29 DPE), the NH_4-N concentrations in the top 30 cm attained close to 10 mg kg^{-1} in the 168 kg ha^{-1} PP-N treatment. By this sampling date, in the treatments with PP-N $\leq$ 112 kg ha^{-1}, the KCl-extractable NH_4-N concentrations attained the soil background concentrations ($<$2 mg kg^{-1}) through the entire depth of sampling (0 to 120 cm). In the soil sampled at or beyond 72 DAA of the PP-N (6 DAE), the KCl-extractable NH_4-N concentrations were not significantly influenced by the N treatments. Furthermore, these concentrations were very close to the soil background NH_4-N levels across all N treatments. In the last sampling very close to the end of the experiment, [i.e. 188 DAA (122 DAE)], the extractable NH_4-N concentrations were well below the background levels in the entire depth of sampling across all treatments. This indicates that NH_4-N from the hydrolysis of urea applied as the PP-N was either taken up by the plant and/or transformed into NO_3-N in the top 120-cm soil profile.

The KCl-extractable NO_3-N concentrations (Figure 6) followed a trend similar to that of NH_4-N. The PP-N rate effect was not clear in the sampling taken on 14 DAA of PP-N (52 DPE). This could be due to a lag time in transformation of urea into NH_4-N and subsequently into NO_3-N. With 168 kg ha^{-1} of PP-N application, the extractable NO_3-N increased to 20 mg kg^{-1} in the top 30 cm of soil by 37 DAA (29 DPE). In this treatment, the NO_3-N concentrations were close to 13 and 20 mg kg^{-1} in the 90 to 120 cm deep soil, during 37 and 72 DAA, respectively (i.e., 29 DPE and 6 DAE). This is an indication of NO_3-N leaching to this depth. In the subsequent samplings, the extractable NO_3-N concentration decreased to soil background levels, of about 5 mg kg^{-1}, across all treatments in the entire soil profile. The results show that under the current experimental conditions of sandy soil, the available soil N decreased drastically within about

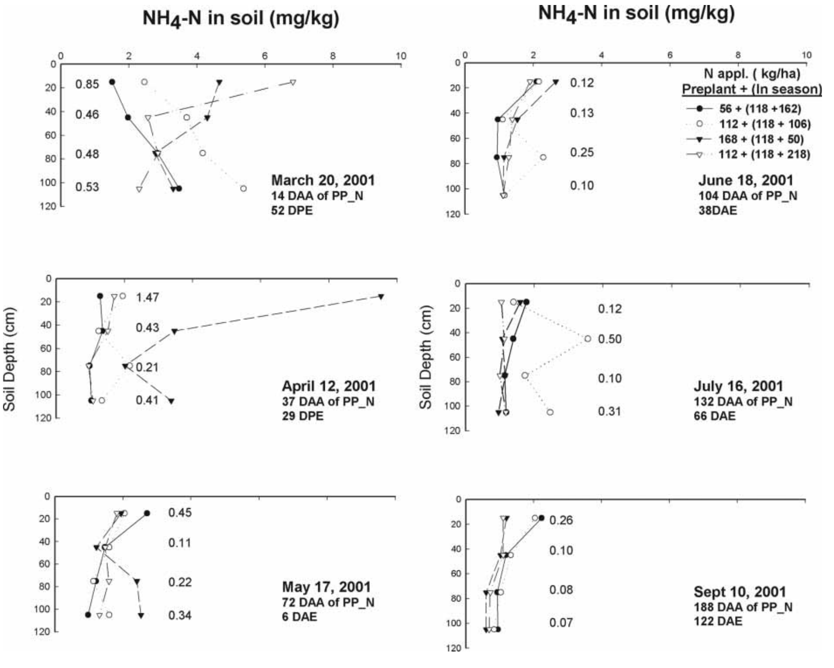

Figure 5. Concentrations of 2M KCl extractable NH_4-N (means across cultivars, in-season N treatments, and replications) in a Quincy fine sandy soil in south-central Washington (Columbia Basin production region in the Pacific Northwest), sampled at a 0- to 120-cm depth (30-cm increments) on 14, 37, 72, 104, 132, and 188 days after application of the preplant N (DAA of PP-N), as influenced by different rates of preplant and in-season N applications to Ranger Russet and Umatilla Russet potato cultivars. (2001 experiment). The standard errors of the means across N-rate treatments at each depth are shown adjacent to each depth data. The error bars could not be drawn because of the small values in comparison to the x-axis scale. DPE = days prior to seedling emergence; DAE = days after emergence.

37 DAA of PP-N (29 DPE) regardless of different rates of PP-N. Therefore, N requirement for the crop during the subsequent growing period had to be supplied by the IS-N applied with irrigation water.

In the 2002 experiment, the extractable NH_4-N and NO_3-N concentrations for the first two samplings (28 and 57 DAA of PP-N, 18 DPE and 11 DAE) were much greater than those in the 2001 experiment (Figures 7 and 8). This difference could be attributed to the difference in fertilizer N applied during the 2 years across different PP-N rates. In the 2001 experiment, the PP-N rates included 56 kg ha^{-1} N as the soil residual N. Therefore, the quantities of fertilizer N applied across 56, 112, and 168 kg N ha^{-1} PP-N treatments were 0, 56, and 112 kg N ha^{-1}, respectively. In contrast, in the 2002 experiment, the soil residual N at the beginning of the experiment was negligible. Therefore, the entire PP-N rates had to be applied as urea N.

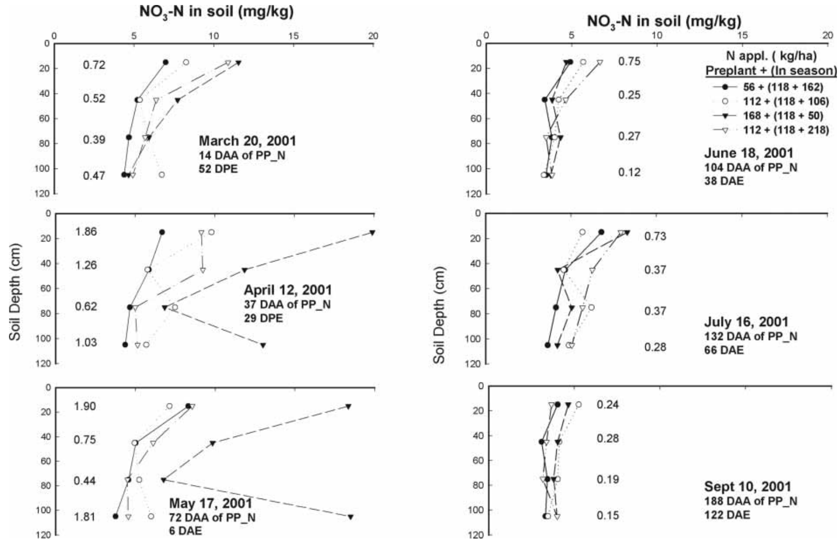

Figure 6. Concentrations of 2M KCl extractable NO_3-N (means across cultivars, in-season N treatments, and replications) in a Quincy fine sandy soil in south-central Washington (Columbia Basin production region in the Pacific Northwest), sampled at a 0- to 120 cm depth (30 cm increments), on 14, 37, 72, 104, 132, and 188 days after application of the preplant N (DAA of PP-N), as influenced by different rates of preplant and in-season N applications to Ranger Russet and Umatilla Russet potato cultivars (2001 experiment). The standard errors of the means across N-rate treatments at each depth are shown adjacent to each depth data. The error bars could not be drawn because of the small values in comparison to the x-axis scale. DPE = days prior to seedling emergence; DAE = days after emergence.

In the soil sampled on 28 DAA (18 DPE), the concentrations of extractable NH_4-N followed the rate of PP-N applications in the top 60-cm depth horizon (Figure 7). In the second sampling (57 DAA, 11 DAE), the N rate effect on the extractable NH_4-N was evident only in the top 30-cm depth sampling. This suggests that by 57 DAA, the PP-N application, most of the NH_4-N was either transformed into NO_3-N form or taken up by the plants. The NO_3-N in the soil was subject to either plant uptake or leached below the sampling depth. During the July through September sampling, the extractable soil NH_4-N concentrations were close to soil background concentrations of about 1–2 mg kg^{-1}, across all N treatments and all depths (Figure 7). This is indicative of limited availability of extractable NH_4^+ form of N shortly after the application of NH_4^+ forming N source.

Rapid transformation of NH_4^+ into NO_3-N form was also observed by an increase in the NO_3-N concentrations in soil sampled 57 DAA of PP-N (11 DAE) as compared to those in the soil sampled 28 DAA (15 DPE) (Figure 8). These NO_3-N concentrations, particularly at the 30 cm depth,

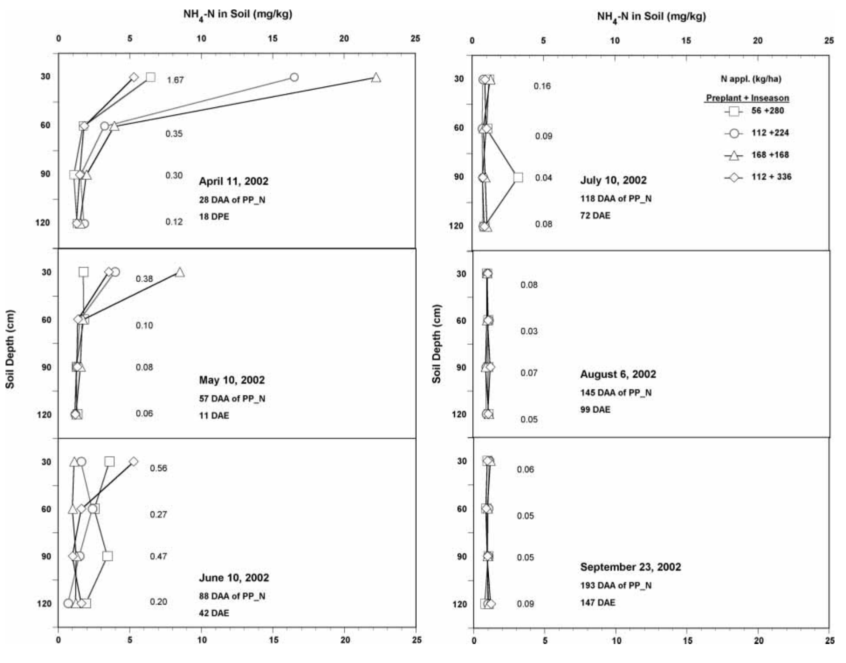

Figure 7. Concentrations of 2M KCl extractable NH_4–N (means across cultivars, in-season N treatments, and replications) in a Quincy fine sandy soil in south-central Washington (Columbia Basin production region in the Pacific Northwest), sampled at a 0- to 120 cm depth (30-cm increments), on 28, 57, 88, 118, 145, and 193 days after application of the preplant N (DAA of PP-N), as influenced by different rates of preplant and in-season N applications to Ranger Russet and Umatilla Russet potato cultivars (2002 experiment). The standard errors of the means across N-rate treatments at each depth are shown adjacent to each depth data. The error bars could not be drawn because of the small values in comparison to the x-axis scale. DPE = days prior to seedling emergence; DAE = days after emergence.

were proportional to the rates of PP-N application. The NO_3-N concentration in the top 30 cm of soil decreased significantly in the soil sampled 88 DAA of PP-N (42 DAE), and the rates of N had no significant effects on the NO_3-N concentrations in the entire soil profile except at the 90-cm depth. These concentrations were between 5 and 10 mg kg^{-1} irrespective of different N-rate treatments. The NO_3-N concentrations continued to decrease in the subsequent soil sampling and were less than 5 mg kg^{-1} across all sampling depths in the soil sampled 145 DAA of PP-N (99 DAE) (Figure 8). July and August is the peak growing season. Therefore, N uptake is quite rapid during this stage of growth. This could contribute to a rapid decline in the available soil N in the soil profile. Furthermore, because of the high temperatures and dry climate, the crop evapotranspiration (ET) is generally quite high during these months. As a result, the irrigation is critical to supply the crop ET.

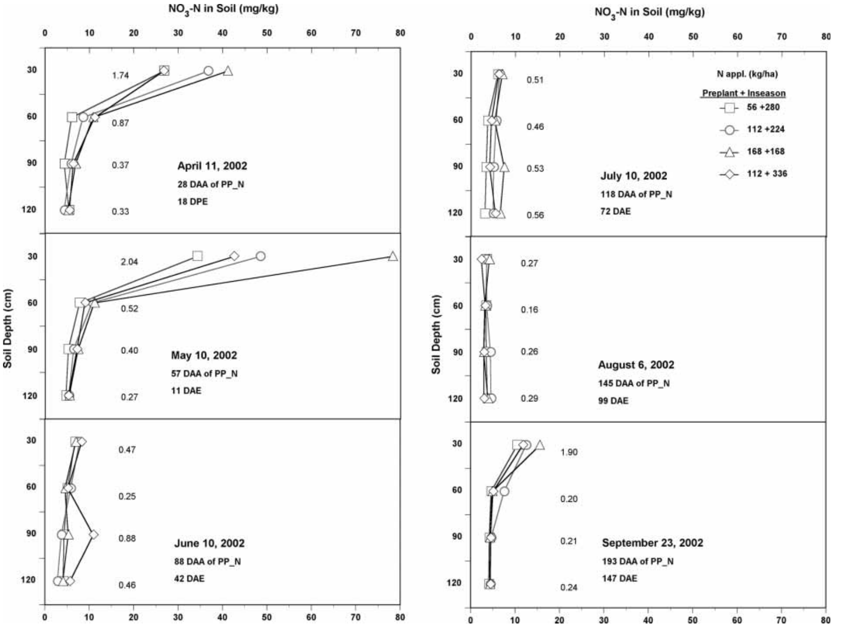

Figure 8. Concentrations of 2M KCl extractable $NO_{3-}N$ (means across cultivars, in-season N treatments, and replications) in a Quincy fine sandy soil in south-central Washington (Columbia Basin production region in the Pacific Northwest), sampled at a 0- to 120-cm depth (30-cm increments), on 28, 57, 88, 118, 145, and 193 days after application of the preplant N (DAA of PP-N), as influenced by different rates of preplant and in-season N applications to Ranger Russet and Umatilla Russet potato cultivars (2002 experiment). The standard errors of the means across N-rate treatments at each depth are shown adjacent to each depth data. The error bars could not be drawn because of the small values in comparison to the x-axis scale. DPE = days prior to seedling emergence; DAE = days after emergence.

Because of high irrigation demand in this period, there is a potential for leaching losses of both water and soluble nutrients below the depth of sampling. The combination of these factors contribute to the low NO_3-N concentration in the entire sampling depth of the soil profile (Figure 8). The September soil sampling, however, shows a slight increase in NO_3-N in the top 60-cm-depth samples. This is indicative of recycling of N from the vegetative residue of the plants. Following August, the aboveground portions of the plants begin to dry and shed leaves. This contributes to a large input of vegetative residue into the surface soil. Decomposition of the vegetative crop residue and subsequent mineralization of organic N into inorganic forms (Alva, Collins, and Boydston 2002) contribute to a slight increase in extractable NO_3-N in the top 30 cm of soil.

CONCLUSIONS

Increased adaptation of new potato cultivars in the PNW, necessitated re-evaluation of N-management recommendations aimed to maximize the production and N-uptake efficiency while minimizing N losses. Two years of study on Ranger Russet and Umatilla Russet cultivars grown on a sandy soil showed no significant difference in tuber yields and/or quality with preplant application of either 56, 112, or 168 kg N ha^{-1} (Alva 2004). Likewise, IS-N application frequency of 2 to 20 split applications during the growing season or total N rates of 336 or 448 kg ha^{-1} (for the entire growing period) had no significant effects on the tuber yield or quality. This study reported that the petiole nutrient concentrations were not significantly influenced by the N-management treatments and thus support the nonsignificant effects of various N-management options on the tuber yield and quality. Petiole concentrations of NO_3-N, P, and K were either within or above the optimal range concentrations. Despite a threefold increase in PP-N rates (50 to 168 kg ha^{-1}), the extractable soil N in the 120-cm-depth soil profile returned to the background levels about 90 days after the N applications. Therefore, the transformation of urea N form is quite rapid in this production system. This study also demonstrates the importance of IS-N application to supply the crop N requirement later during the growing period.

ACKNOWLEDGEMENTS

The author appreciates the support and cooperation by our industry partners, AgriNorthwest Company, Kennewick, WA, who provided the site and other field assistance to carry out this study in a commercial production condition. Special thanks to Martin Moore of AgriNorthwest Company Research Department for cooperation with all plant analysis. The author also appreciates Marc Seymour, William Boge, Louis Faro, Melanie Wilson, and Tami Baugh for assistance with this study and preparation of the manuscript.

REFERENCES

Alva, A.K. (2004) Effects of pre-plant and in-season nitrogen management practices on tuber yield and quality of two potato cultivars. *Journal of Vegetable Crop Production*, 10: 43–60.

Alva, A.K., Collins, H.P., and Boydston, R.A. (2002) Corn, wheat, and potato crop residue decomposition and nitrogen mineralization in sandy soils under an irrigated potato rotation. *Communications in Soil Science and Plant Analysis*, 33: 2643–2651.

Dean, B.B. (1993) *Managing the Potato Production System*; Food Products Press: Binghamton, NY.

Dow, A.I., Halvorson, A.R., Thornton, E.R., and Roberts, S. (1974) *Fertilizer Guide: Irrigated Potatoes for Central Washington*; Washington State Extension Service, Washington State Agriculture Experiment Station: Pullman, WA, P. 7.

Gardener, B.R. and Jones, J.P. (1975) Petiole analysis and nitrogen fertilization of Russet Burbank potatoes. *American Potato Journal*, 52: 195–200.

Khakural, B.R. and Alva, A.K. (1996) Transformation of urea and ammonium nitrate in an Entisol and a Spodosol under citrus production. *Communications in Soil Science and Plant Analysis*, 27: 3045–3057.

Knight, C.W. and Sparrow, S.D. (1993) Urea nitrogen budget for a subarctic agricultural soils. *Soil Science Society of America Journal*, 57: 1138–1144.

Lang, N.S., Stevens, R.G., Thornton, R.E., Pan, W. L., and Victory, S. (1999) *Potato Nutrient Management for Central Washington*; Washington State University Cooperative Extension Bulletin, Washington State University: Pullman, WA, p. 17.

National Potato Council. (2004). *Potato statistical yearbook, 2003–2004*. National Potato Council: Washington, DC, 2004, 88.

Porter, G.A. and Sisson, J.A. (1991) Petiole nitrate content of Maine grown Russet Burbank and Shepody potatoes in response to varying nitrogen rate. *American Potato Journal*, 68: 493–505.

Roberts, S. and Cheng, H.H. (1988) Estimation of critical nutrient range of petiole nitrate for sprinkler-irrigated potatoes. *American Potato Journal*, 65: 119–124.

Roberts, S. and Dow, A.I. (1982) Critical nutrient ranges for petiole phosphorus levels of sprinkler irrigated Russet Burbank potatoes. *Agronomy Journal*, 74: 583–585.

Sankhayan, S.D. and Shukla, U.C. (1976) Rates of urea hydrolysis in five soils of India. *Geoderma*, 16: 171–178.

U.S. Department of Health, Education, and Welfare (1962). *Public health service drinking water standards*; Publication 956. Washington, DC: U.S. Department of Health, Education, and Welfare.

USGS. (2004). *National Water Quality Assessment* (*NAWQA*) *Program*; http://water.usgs.gov/nawqa/nawamap.html.

Vitosh, M.L. and Silva, G.H. (1994) A rapid petiole sap nitrate-nitrogen test for potatoes. *Communications in Soil Science and Plant Analysis*, 25: 183–190.

Vitosh, M.L. and Silva, G.H. (1996) Factors affecting potato petiole sap nitrate tests. *Communications in Soil Science and Plant Analysis*, 27: 1137–1152.

Washington State Cooperative Extension. (2003a). *Pacific Northwest Weed Management Handbook*. Pullman, WA: Cooperative Extension, Washington State University.

Washington State Cooperative Extension. (2003b). *Pacific Northwest Insect Management Handbook*. Pullman, WA: Cooperative Extension, Washington State University.

Washington State Cooperative Extension. (2003c). *Pacific Northwest Disease Control Handbook*. Pullman, WA: Cooperative Extension, Washington State University.

Westcott, M.P., Stewart, V.R., and Lund, R.E. (1991) Critical petiole nitrate levels in potato. *Agronomy Journal*, 83: 844–850.

Westcott, M.P., Rosen, C.J., and Inskeep, W.P. (1993) Direct measurement of petiole sap nitrate in potato to determine crop nitrogen status. *Journal of Plant Nutrition*, 16 (3): 515–521.

Westermann, D.T. (1993) Fertility management. In *Potato Health Management*; Rowe, R.C. (ed.), APS Press: St. Paul, MN, 77–86.

Williams, C.M.J. and Meir, N.A. (1990) Determination of the nitrogen status of irrigated potato crops, 1: Critical nutrient ranges for nitrate-nitrogen in petioles. *Journal of Plant Nutrition*, 13: 971–984.

Yadav, D.S., Kumar, V., Singh, M., and Relan, P.S. (1987) Effect of temperature and moisture on kinetics of urea hydrolysis and nitrification. *Australian Journal of Soil Research*, 25: 185–191.